Monitoring a Gravity-Flow Conveyance System to Improve Water Management. Lis Valley Irrigation District Case Study

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Abstract. This paper presents a study of the monitorization of the conveyance system of the collective water network in the framework of the Lis Valley Water Management Operational Group, aiming the improvement of water management by the Water Users' Association. The methodology considered the measurement of water allocation to main canals, its distribution throughout the conveyance system, and the on-farm irrigation demand. This paper presents the results of Canal 2, for 2019 and 2020 irrigation seasons. This canal supplies an area of 410 ha, is gravity-fed from Lis river, on the Arrabalde weir, in Leiria, and has a pumping recharge during the irrigation peak period. A water balance of supply and irrigation demand was carried out at 10-day period, to evaluate the performance of the distribution water management. The analyzed system reveals the specificity of the drainage water reuse, which leads to a more flexible management of water allocated by gravity-fed, and rational of pumping supply, in order to adjust it to irrigation demand, through energy consumption. Results point to actions that prioritize consolidating the improvement management of water resources, like the implementation of optimal operational plans to adjust the water demand with distribution, accompanied with the improvement of the on-farm irrigation systems.

Keywords: Hydraulic monitoring · Water demand · Canal distribution · Water Users' Association · Lis Valley

1 Introduction

Conveyance canals distribution in irrigation districts have specific operative characteristics. According to the farmers' calendars of irrigation, which aim to achieve equitable water partition, the management becomes complex when water flow is manually controlled. The water management in irrigation districts without upstream reservoirs is based in water running availability, according to inlet flows, which requires high distribution flexibility on the collective conveyance. In this case, water reuse from the drainage ditches allows mitigating the water shortage. Under such conditions, these

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J. R. da Costa Sanches Galvão et al. (Eds.): *Proceedings of the 1st International Conference on Water Energy Food and Sustainability (ICoWEFS 2021)*, pp. 821–831, 2021.
https://doi.org/10.1007/978-3-030-75315-3_87

systems require a highly interactive management approach between the water users association and the farmer-beneficiaries themselves [1]. The rational management of collective irrigation should be based on an information system, with data from field monitoring of irrigation water volumes demanded and supplied, energy consumed on pumping, and costs of infrastructure maintenance. Several examples of models and procedures have been developed and applied: Playán et al. [2] developed a database tool for enhancing irrigation district management; and Mateos et al. [3] presented a scheme irrigation management information system.

The irrigation system of Lis Valley does not have an upstream reservoir, guaranteeing the water supply during the irrigation peak period. The water available in the summer is from river basic flow runoff, being its water managed by weirs, which allow a temporary reservoir and level control for gravity-fed and pumping irrigation. The water reuse is an endemic process, where the drainage water returns back to the river, recharging its flow downstream, which can be used again for irrigation. This water reuse through the irrigation pumping, from drainage ditches, allows mitigating the water shortage. In this context, the usual meaning of "water losses" is not valid, since the main criteria for managing water distribution is not to minimise the water losses, but instead, to optimise the equity of spatial water distribution, guaranteeing that all farmers have the conditions to avoid water stress at plot level.

This paper presents a monitoring study of "Canal 2" supply of the Lis Valley Irrigation District, on 2019 and 2020 irrigation seasons, carried out on the framework of an Operational Group of EIP-AGRI [4]. This study considered the measurement of gravity-fed and pumping continuous discharges, the off-farm distribution, the on-farm irrigation demand, and the assessment of demand-supply balance.

2 Materials and Methods

2.1 Study Area

Lis Valley Irrigation District (LVID) is a public irrigation district managed by a Water Users' Association (WUA), and located in the Coastal Center of Portugal [5]. The total area is about 2000 ha, and the main crops are forage corn, forage grass, horticultural, orchards, and rice. The hydraulic infrastructures have the objectives of perimeter drainage defense through slope collectors and valley ditches, the irrigation water supply through a canal conveyance system, and the field drainage based on a ditch network. Water is supplied by an open-channel conveyance network from weirs installed along the Lis river and tributaries, having the primary network with a length of about 44.5 km, and by pumping from drainage ditches.

The water conveyance and distribution for the irrigation district is subdivided into supply sectors, comprised by a main canal, gravity-fed by a river diversion from a weir. During the irrigation peak period, the downstream areas of some supply sectors are not fully supplied, so recharging water from the river or drainage ditches is pumped to reinforce canals flows (Fig. 1). A main canal and a set of small lined or earthen secondary channels to distribute the water to the field hydrants compose each sector. The supply of secondary channels is ensured by duckbill structures to control water level in the main canal (Fig. 1a).

Despite the monitoring work has been applied to the entire irrigation district, Canal 2 was selected to be presented, corresponding to the sectors C2A and C2B (Fig. 2). The Canal 2 is gravity-fed, upstream, on the Arrabalde weir of Lis river, in Leiria city, a section with a limited flow. Downstream Arrabalde there are two tributaries, Lena and Milagres rivers. Canal 2 flow is recharged at the Necessidades Pumping Station (here referred by Necessidades), located 7 km downstream the Arrabalde weir, corresponding to the supply of C2B sector (Fig. 2b,c and Table 1).

Fig. 1. Conveyance system infrastructures: (a) duckbill water level controller, of Canal 2; (b) river weir on Necessidades pumping station; (c) canal reinforcement by pumping at Necessidades.

Table 1. Canal 2 and sectors C2A and C2B characteristics.

Sector	Area (ha)	Canal length (km)	Max. canal heigth (cm)	Max. canal discharge (L/s)	Max. pumping discharge (L/s)
C2A	195.5	4.8	0.75	380	–
C2B	214.7	4.4	0.70	350	150

2.2 Water Supply

The methodology for monitoring the water supply system for irrigation was based on a network of observations to assess the flow rates at strategic points. Flow measurements in canals and pumping stations followed methodology previously published [6], including the observations of operative daily management practices.

For the evaluation of the canals' flows, the canal section velocity method was used. The measurements were performed with the TELEDYNE ISCO 2150 Area Velocity Flow Module and Sensor, which obtains the flow velocity based on the emission of ultrasonic waves together with the Doppler effect (Fig. 3a). In order to obtain a continuous flow measurement, water level sensors were installed in the studied sections of the canals. These sensors record the total pressure, obtaining the respective height of the water by the

difference with the value of the atmospheric pressure, measured simultaneously. Based on flow curves calibrated for each section (with the flowmeter), continuous hydrographs were obtained corresponding to water levels measurement, allowing to know the daily variation of the flow level in the canal. These field measurements followed the procedures presented by Replogle et al. [7]. The discharge measurement on the upstream section of Canal 2 was made continuously by the ISCO 2150 sensor, located on a buried pipe component that supplies the open main canal (Fig. 3b).

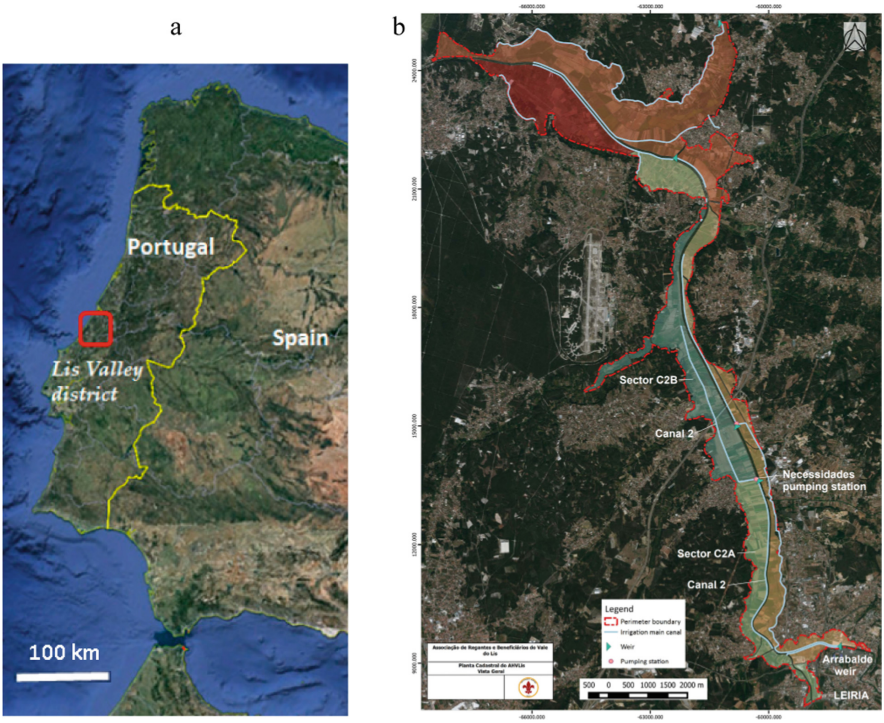
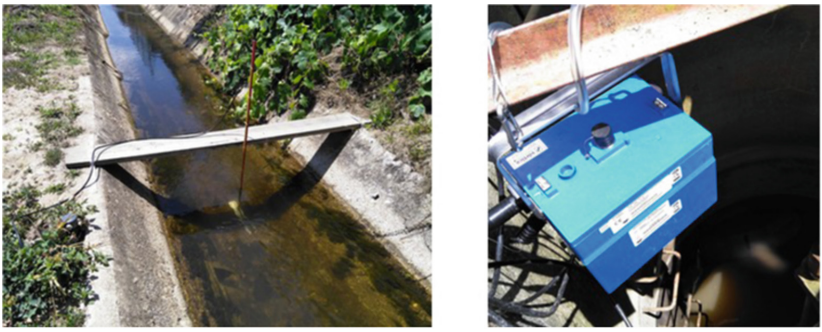


Fig. 2. (a) Location of the Lis valley irrigation district in Portugal (red square) (source: Google Maps, https://maps.google.pt); (b) Location of Canal 2 and Sectors C2A and C2B, in Lis Valley Irrigation District (source: Lis Valley Irrigation District Water Users' Association).

2.3 Irrigation Water Demand

Water demand during the irrigation season was obtained based in meteorological data (reference evapotranspiration, ET_0, and precipitation, P) from three stations positioned along the valley. The analysis was applied between May and October, with a 10-day (decade) time step. The crop evapotranspiration (ET_c) of each sector, corresponding to the water used by the crop consumptively, was calculated applying the crop coefficient (Kc) to the reference evapotranspiration ($ET_c = ET_0 \times Kc$). To obtain a global crop coefficient to each sector, the different crop occupation was recognized based on WUA

records, allowing a weighted crop coefficient. The evolution of Kc along crop growth stages was considered according to the usual sowing dates practiced [8]. The net irrigation demand (NID) was calculated by the difference between ET_c and precipitation ($ET_c - P$), assuming that the initial soil water and the groundwater capillary rise contributions were not significant.



(a) (b)

Fig. 3. Flow measurements in canals and pumping stations with ultrasonic flow meter: (a) used as portable device on an open canal section; (b) used fixed on a buried pipe.

3 Results

3.1 Water Supply

The Canal 2 water supply to C2A and C2B sectors in the mid-season months (July and August, of 2019 and 2020) is presented in Fig. 4. Hydrographs of upstream section (C2A inflow) evidence a responsive operation of the water uptake in the weir with the meteorological conditions.

A day/night oscillation of the inflow was observed throughout the whole period, being the night records about 30 to 50% of daytime ones. The main gate of Canal 2 in the Arrabalde weir was programmed to take into account this reduction in the use of on-farm irrigation water at night. Day of higher evaporative demand, corresponded to a higher distribution to on-farm irrigation, and, in consequence, an higher difference between upstream and downstream discharges (e.g. 11st July 2019, or 17th July 2020). On the other hand, on rainy days, this difference was reduced (e.g. 21st July 2019, or 20th August 2020). During rainy days, the response of allocation reduction is unclear; the summer rains are usually occasional, not spatially uniform and of small depth. Therefore, for precaution, it is normal to maintain the collective distribution, and the irrigation adjustments carried out by farmers, according to specific on-farm requirements.

The supply discharge data of C2B sector, including the Canal 2 discharge upstream Necessidades pumping station and the reinforcement of this pumping, are presented in Fig. 5. The pumping period is comprised from early July to mid-September. Necessidades station is composed by two pumps, each one with 75 L/s of discharge capacity. Usually

pumping period starts at 8:00 am and ends at 6:00 pm. At days with higher demand, both pumps may work together for a few hours, and when the demand is reduced, the daily pumping period decreases up to zero. The monitoring of the distribution of the water to each one of the irrigated parcels is very complex, since it involves the commitment of a high number of local farmers that do not have records of irrigation time and discharges. Even those who choose to pump from drainage ditches to facilitate pressurized irrigation systems do not have those record.

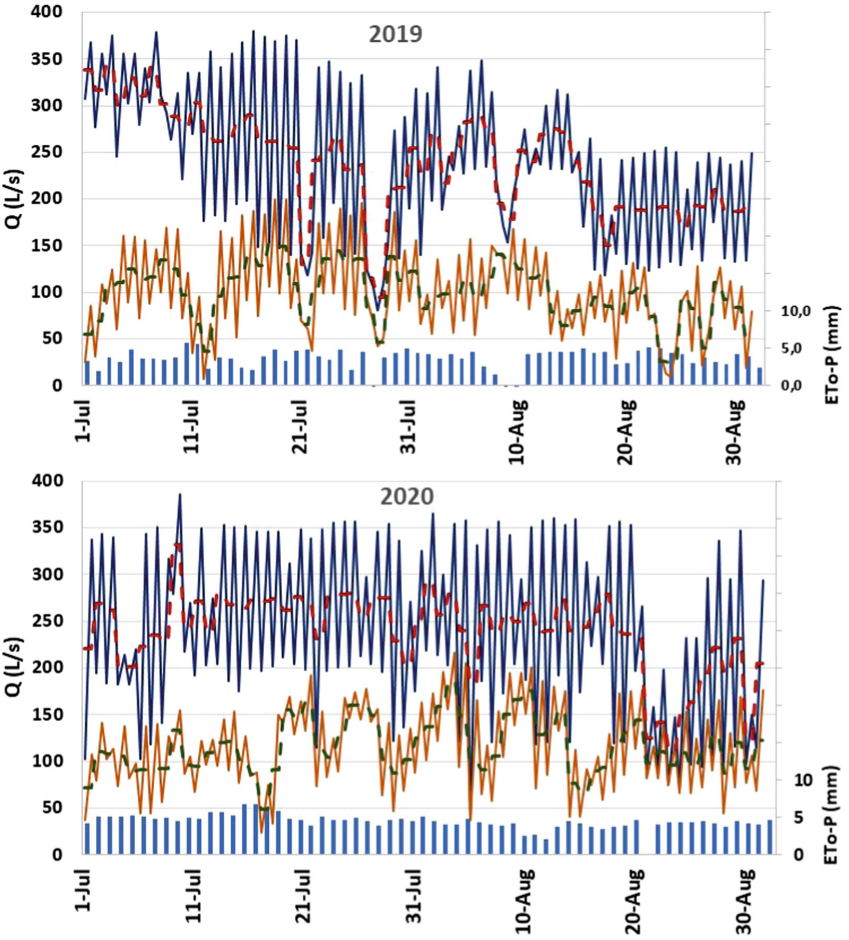


Fig. 4. Measured discharges (L/s) at Canal 2, in 2019 and 2020: C2A supply: —continuous, —daily average; C2B supply: —continuous, —daily average; —ET_0 - P (mm).

The real-time operation of the collective distribution system at sector level, depends of on-farm irrigation demand, related with the crop development, soil and climatic conditions, and the field irrigation system. This operation is based on a strong cooperation between the WUA and the farmers, to get the best water distribution to the several field

parcels of the same branch canal. In practice, adjustments are made in real time, with both dynamic adjustments between supply and demand and distribution of water being based on the empirical knowledge of off- and on-farm water losses, and the cooperation between farmers on the same canal branch to share the water available.

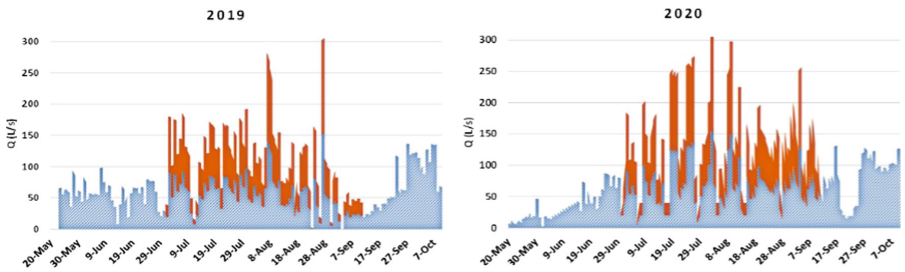


Fig. 5. Supply discharge of C2B sector, on 2019 and 2020: gravity-fed discharge from upstream component of Canal 2 (not used on C2A sector); pumping by Necessidades.

3.2 Irrigation Water Demand

The average C2A and C2B 10-days crop coefficients are present in Table 2. The crop pattern followed the data presented by Ferreira et al. [9]. Sowing and harvesting schedule of annual crops was assigned considering the common practices in the area. Crop coefficients were estimated considering maximum production, without water stress. Table 3 presents the 10-days meteorological data and crop evapotranspiration for 2019 and 2020. There is a contrast in the meteorological conditions of these two years, leading to a maximum water demand period in August 2019, whereas in 2020 it occured in July. Crop water demand was assessed by the Net Irrigation Demand NID = ET_c–P, a simplified approach, neglecting the capillary rise contribution and the initial soil water storage use. When NID had negative values, it means that in the 10-days period, precipitation exceeded the ET_c. However, a daily analysis in the same period, might reveal the need to irrigate some crops, because the precipitation occours occasionally.

3.3 Sector Water Balance

Comparing the supply and the demand data on the C2A sector, for 10-days periods, of the irrigation seasons of 2019 and 2020 (Fig. 6), it is concluded that the supply significantly exceeded the demand, in many periods. There are several factors that explain this oversupplying practice. On the one hand, being a gravity-fed allocation, this does not entail any additional cost for WUA. On the other hand, being the conservation status of the canal in certain places deficient, leading to uncontrollable water losses to the drainage network. This water that apparently is lost to the drainage network, could be reused during the periods of greatest water shortage, especially when using pressure irrigation systems, pumping from the drainage ditches. Therefore, this recharge of the drainage network is largely a beneficial use of water. In addition, these drainage ditches flow into

Table 2. Crop coefficients of C2A and C2B sectors (10-days period)

Crop	Area (%)		May			June			July			August			September		
	C2A	C2B	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Corn	43	33	0.30	0.30	0.40	0.50	0.60	0.70	0.90	1.00	1.00	1.00	1.00	1.00	0.90	0.80	0.60
Pasture	7	24	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Vegetab	14	11	0.80	0.80	0.80	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Rice	0	15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fruits	36	17	0.40	0.50	0.60	0.70	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.80	0.70
Kc (C2A)			0.43	0.47	0.58	0.69	0.75	0.79	0.88	0.92	0.92	0.92	0.92	0.92	0.86	0.81	0.68
Kc (C2B)			0.61	0.63	0.71	0.78	0.81	0.85	0.92	0.95	0.95	0.95	0.95	0.95	0.90	0.85	0.77

Table 3. Meteorological data and net irrigation demand per sector C2A and C2B, for the 10-days period of 2019 and 2020

		May			June			July			August			September		
		1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
		2019														
ET_0		35.2	45.1	54.2	41.6	38.8	35.9	36.9	36.9	45.4	36.6	42.0	42.1	39.2	32.7	25.8
P		12.0	0.6	1.0	12.2	3.4	6.0	0.0	0.6	6.2	11.6	0.0	0.0	0.0	7.0	21.8
NID	C2A	3.1	20.6	30.5	16.5	25.7	22.4	32.5	33.4	35.5	22.1	38.7	38.8	33.7	19.5	−4.3
	C2B	9.5	27.8	37.5	20.2	28.0	24.5	33.9	34.5	36.9	23.2	39.9	40.0	35.3	20.8	−1.9
2020																
ET_0		18.6	22.3	22.0	40.2	41.4	40.4	49.3	56.7	51.0	39.1	35.7	47.0	42.3	31.5	25.6
P		21.8	12.8	15.2	0.2	4.2	0	0	0	0.4	0	0.2	20.4	0	43.6	2.8
NID	C2A	−13.8	−2.3	−2.4	27.5	26.9	31.9	43.4	52.2	46.5	36.0	32.7	22.8	36.4	−18.1	14.6
	C2B	−10.5	1.3	0.5	31.2	29.4	34.3	45.4	53.9	48.1	37.2	33.7	24.2	38.1	−16.8	16.9

ET_0, Reference evapotranspiration (mm); P, Precipitation (mm); NID, Net irrigation demand (mm).

the River Lis upstream from the Salgadas weir, being reused for irrigation. These factors explain the differences observed between supply and demand.

Comparing the corresponding supply and the demand data on the C2B sector (Fig. 7), it is concluded that the supply matches relatively well with the on-farm demand. Contrarely to the sector C2A, the pumping supply is operationally well adjusted to the irrigation demand, because this allocation has a high cost charge for WUA. Effectively, the pumping has an important role in water supply, particularly at daytime.

4 Final Considerations

The good practice of water management in an irrigation district should be based on the knowledge of water supply, its off-farm distribution and use at on-farm level. Therefore, monitoring plays a decisive role in improving water management, as it allows the identification of problems in the infrastructure, in the operational practices, and, especially, in the critical situations during the irrigation peak period.

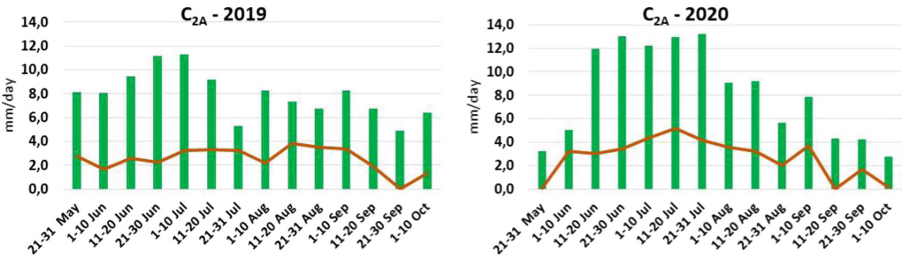


Fig. 6. Gravity-fed supply (, mm/day) and net irrigation demand (, mm/day) of sector C2A, for 2019 and 2020 irrigation seasons.

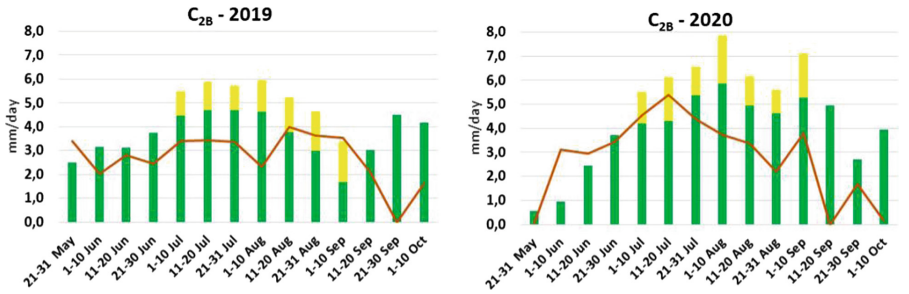


Fig. 7. Gravity-fed supply (, mm/day), pumping recharge (, mm/day) and net irrigation demand (, mm/day) of sector C2B, for 2019 and 2020 irrigation seasons.

Lis river has no regularization by reservoirs, and the flow suffers a significant decrease in the summer period. Given this reality, irrigation water management is based on quasi-real-time supply adjustment in the very short time of a few hours or a few days. It takes into account the relative independence of the supply of several sectors, allowing higher

flexibility and cooperation among the group of users at secondary canal level, facilitating the management and favor the equity of water distribution. The supply water scarcity risk and the deficiency of the conveyance system lead to the need of recharge pump stations from drainage water. So, the drainage system also works complementary with the irrigation one, like a off-field water reservoir, allowing the pumping directly from the ditches to the farmers' private pressurized systems. The monitoring of this system provides information and knowledge leading to a more flexible management of water allocated by gravity-fed and rational of pumping supply, to adjust it to irrigation demand through energy consumption. These results point to guidelines to consolidate improved water management: better maintenance and conservation of hydraulic infrastructures to reduce water losses and better flow control; implementation of optimal operational plans, to adjust the water demand with distribution; improvement of the on-farm systems with better water application control and maintenance procedures, reducing labor and increasing the distribution uniformity, applying irrigation scheduling plans based on monitoring systems; and improvement of water quality control on the water reuse from drainage ditches.

Acknowledgments. Project "Lis Valley Water Management Operational Group" ("PDR2020-1.0.1-FEADER-030911 – Grupo Operacional para a gestão da água no Vale do Lis"), funded by IFAP/PDR2020, Measure Innovation, Intervention Operational Groups.

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